

The Assurance Challenges of Advanced Packaging Technologies for Electronics

Michael J. Sampson

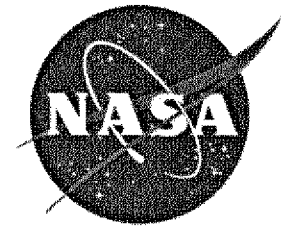
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Advances in microelectronic parts performance are driving towards finer feature sizes, three-dimensional geometries and ever-increasing number of transistor equivalents that are resulting in increased die sizes and interconnection (I/O) counts. The resultant packaging necessary to provide assemble-ability, environmental protection, testability and interconnection to the circuit board for the active die creates major challenges, particularly for space applications. Traditionally, NASA has used hermetically packaged microcircuits whenever available but the new demands make hermetic packaging less and less practical at the same time as more and more expensive. Some part types of great interest to NASA designers are currently only available in non-hermetic packaging. It is a far more complex quality and reliability assurance challenge to gain confidence in the long-term survivability and effectiveness of non-hermetic packages than for hermetic ones. Although they may provide more rugged environmental protection than the familiar Plastic Encapsulated Microcircuits (PEMs), the non-hermetic Ceramic Column Grid Array (CCGA) packages that are the focus of this presentation present a unique combination of challenges to assessing their suitability for spaceflight use. The presentation will discuss the bases for these challenges, some examples of the techniques proposed to mitigate them and a proposed approach to a US MIL specification Class for non-hermetic microcircuits suitable for space application, Class Y, to be incorporated into MIL-PRF-38535. It has recently emerged that some major packaging suppliers are offering hermetic area array packages that may offer alternatives to the non-hermetic CCGA styles but have also got their own inspectability and testability issues which will be briefly discussed in the presentation.



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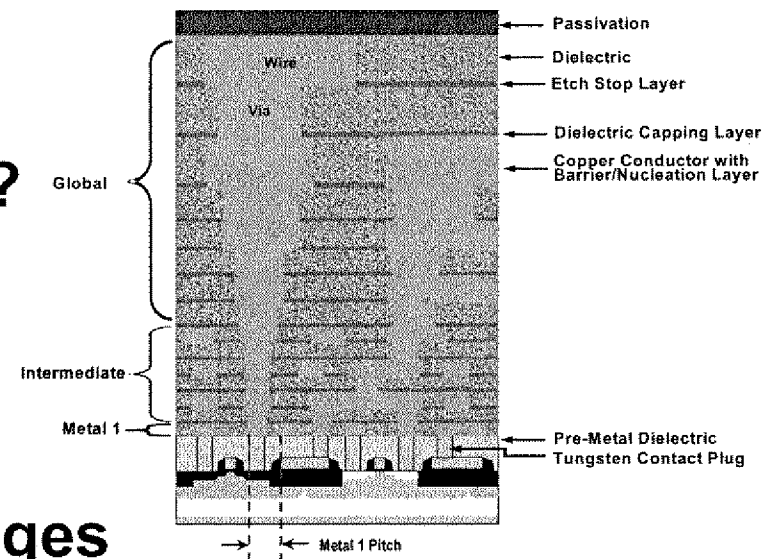
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Outline

- **What is Electronic Packaging?**
- **Why Package Electronic Parts?**
- **Evolution of Packaging**
- **New Application Challenges and Solutions**
- **Associated Assurance Challenges**
- **NEPP Activities**
- **The Class Y Concept and Possible Extensions**
- **Embedded Technologies**
- **NEPP Activities**

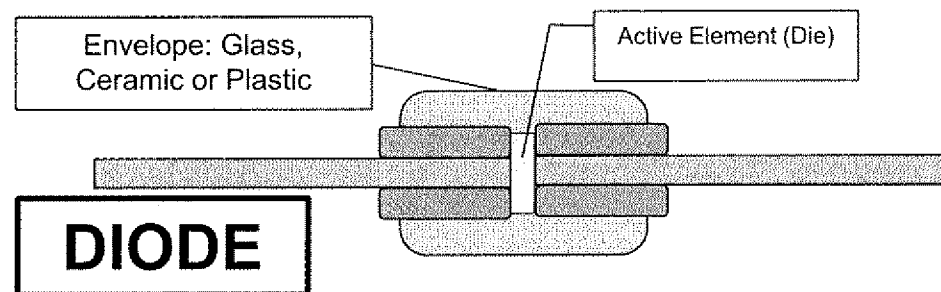
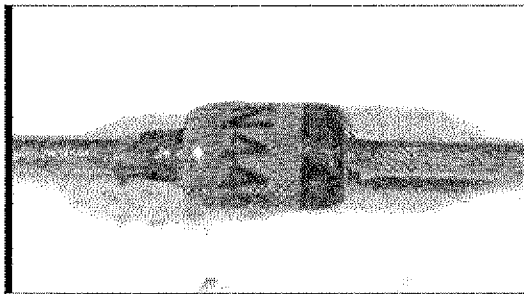


What is Electronic Packaging?


- **Electronic “Packaging” can have two basic meanings:**
 - **First (Part) Level: The “envelope” of protection surrounding an active electronic element, and also the termination system to connect it to the outside world**
 - **Second and Higher Levels: The assembly of parts to boards, boards to slices, slices to boxes, boxes to systems, instruments and spacecraft**
- **This discussion covers examples of both**

Why Package Electronic Parts?

- To protect the active element against:
 - Handling
 - Shock and vibration
 - Contamination
 - Light penetration or emission
- To provide a suitable system to make connection between the element and the printed wiring board
- To prevent conductive parts of the element from coming in contact with other conductive surfaces, unless intended



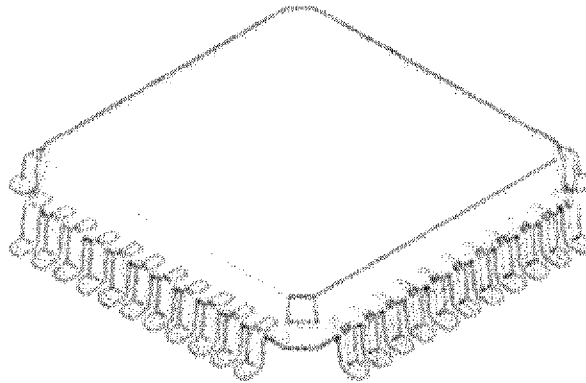
Package Options – Hermetic?

- Once, hermetic packages were the preferred option
- Now, few hermetic options for latest package technologies
 - Development of new hermetic options unattractive
 - Very high Non Recurring Expenses
 - Very high technical difficulty
 - Very low volume
 - Demanding customers
- Market is driven by consumer products
 - Low cost
 - High volume
 - Rapid turnover
 - “Green”
 - Minimized size

= Non hermetic, mostly plastic
- New hermetic technologies may become available but timing is uncertain

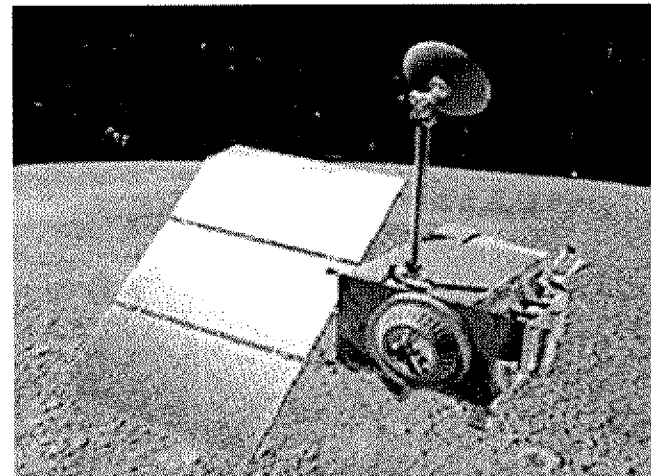
The “General” Package

- Typically, packages consist of the same basic features but achieve them in many ways:
 - Functional elements - active die, passives etc.
 - Interconnects between elements (2 or more elements)
 - A substrate
 - Interconnects to the external I/O of the package
 - A protective package
 - Interconnects to the next higher level of assembly



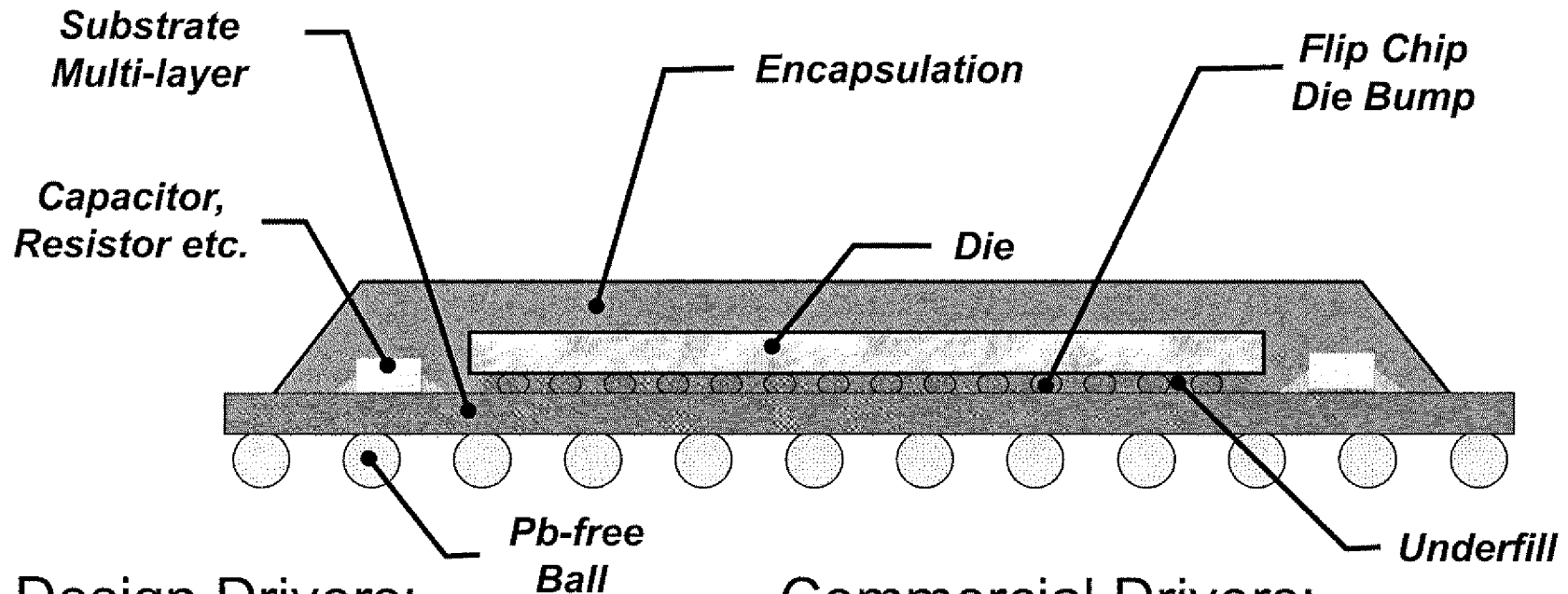
Continuous Packaging Challenges

- I/O s, increasing number, decreasing pitch
- Heat Dissipation, (especially in space)
- Manufacturability
- Materials
- Mechanical
- Installation
- Testability
- Inspectability
- RoHS (Pb-free)
- (Space Environment)



*—Lunar Reconnaissance Orbiter (LRO), Built at GSFC,
Launched with LCROSS, June 18, 2009*

Commercial, Non-hermetic Package (PBGA*)



Design Drivers:

- High I/O count
- Large die
- Environmental protection
- Performance/Speed
- Ancillary parts

Commercial Drivers:

- Low cost
- High volume
- Limited life
- Automated installation
- Compact

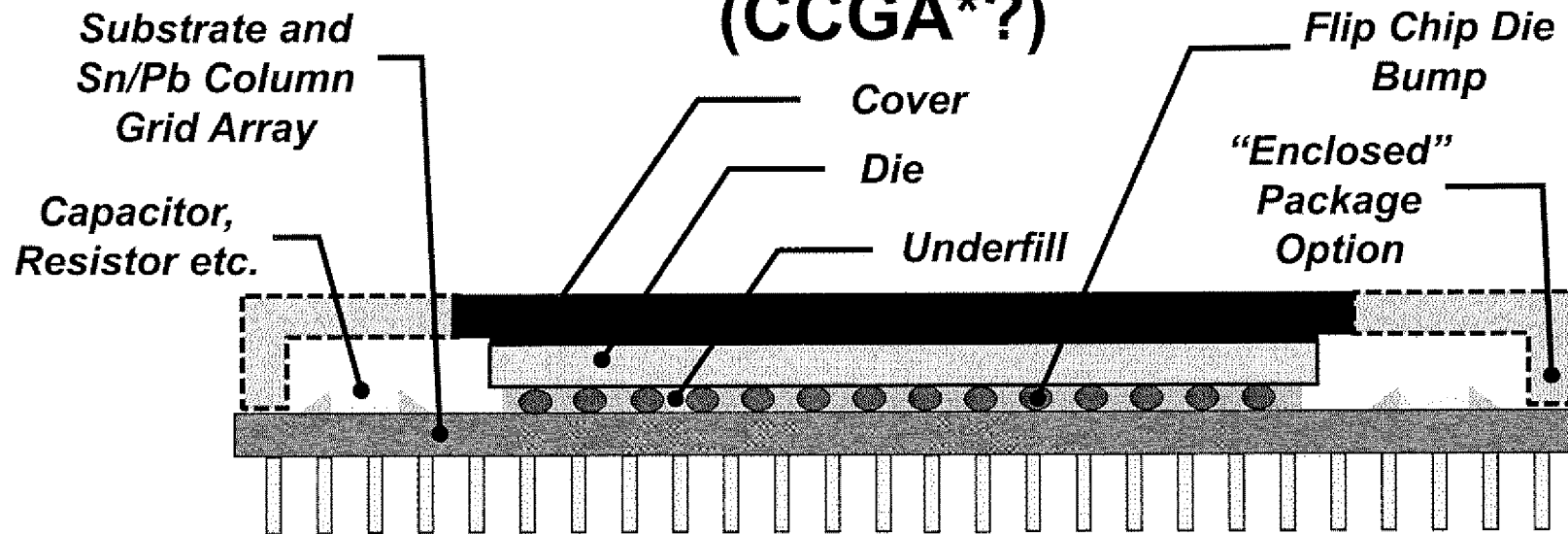
* PBGA: Plastic
Ball Grid Array

Space Challenges for Complex Non-hermetic Packages

- **Vacuum:**
 - Outgassing, offgassing, property deterioration
- **Foreign Object Debris (FOD)**
 - From the package threat to the system, or a threat to the package
- **Shock and vibration**
 - During launch, deployments and operation
- **Thermal cycling**
 - Usually small range; high number of cycles in Low Earth Orbit (LEO)
- **Thermal management**
 - Only conduction and radiation transfer heat
- **Thousands of interconnects**
 - Opportunities for opens, intermittent - possibly latent
- **Low volume assembly**
 - Limited automation, lots of rework
- **Long life**
 - Costs for space are high, make the most of the investment
- **Novel hardware**
 - Lots of “one offs”
- **Rigorous test and inspection**
 - To try to find the latent threats to reliability

***ONE STRIKE
AND YOU'RE
OUT!***

Non-hermetic Package, With "Space" Features (CCGA*?)



Space Challenge	Some Defenses
Vacuum	Low out/off-gassing materials. Ceramics vs polymers.
Shock and vibration	Compliant / robust interconnects - wire bonds, solder balls, columns, conductive polymer
Thermal cycling	Compliant/robust interconnects, matched thermal expansion coefficients
Thermal management	Heat spreader in the lid and/or substrate, thermally conductive materials
Thousands of interconnects	Process control, planarity, solderability, substrate design
Low volume assembly	Remains a challenge
Long life	Good design, materials, parts and process control
Novel hardware	Test, test, test
Rigorous test and inspection	Testability and inspectability will always be challenges

* Ceramic Column Grid Array

Hermeticity

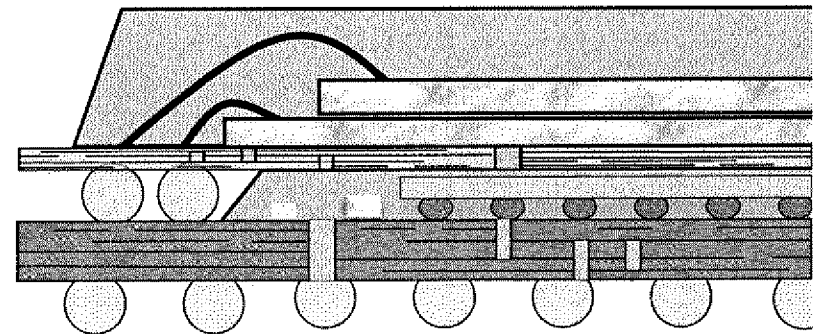
- **NASA prefers hermetic packages for critical applications**
- **Hermeticity is measureable, assuring package integrity**
- **Only 3 tests provide assurance for hermetic package integrity:**
 - Hermeticity – nothing bad can get in
 - Residual or Internal gas analysis – nothing bad is inside
 - Particle Impact Noise Detection – no FOD inside
- **NON-HERMETIC PACKAGE INTEGRITY IS HARD TO ASSESS - NO 3 BASIC TESTS**
- **Non-hermetic packages expose materials' interfaces that are locked away in hermetic ones**

But What is Hermetic?

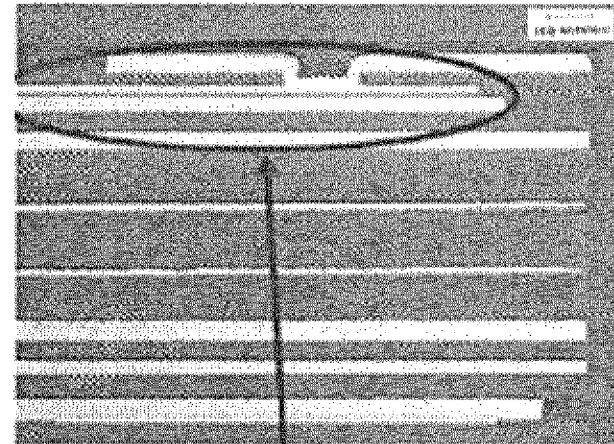
- **Per MIL-PRF-38534 Appx E and 38535 Appx A, hermetic packages must consist of metals, ceramic and glass in combinations ONLY, no polymerics**
- **Meets aggressive leak rate test limits**
 - Verifies low rate of gas escape/ atmospheric interchange
 - Even so, small volume packages meeting “tight limits” theoretically exchange their atmosphere very quickly:
 - 0.001 cc, exchanges 93% in 1 month at 5×10^{-8} atmosphere/cc/sec!
 - 1.0cc, 96% in 10 years at 1×10^{-8}
 - Even large packages with quite small leaks can surprise
 - 10 cc, 96% in 1 year at 1×10^{-6} !
- **For applications in space vacuum why care?**
 - Risk for contamination on the ground
 - Risk for outgassing in vacuum

Non-hermetic Package Variations

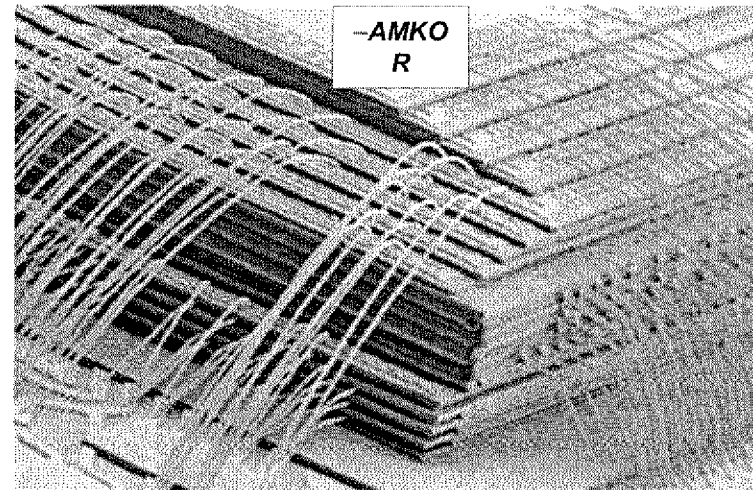
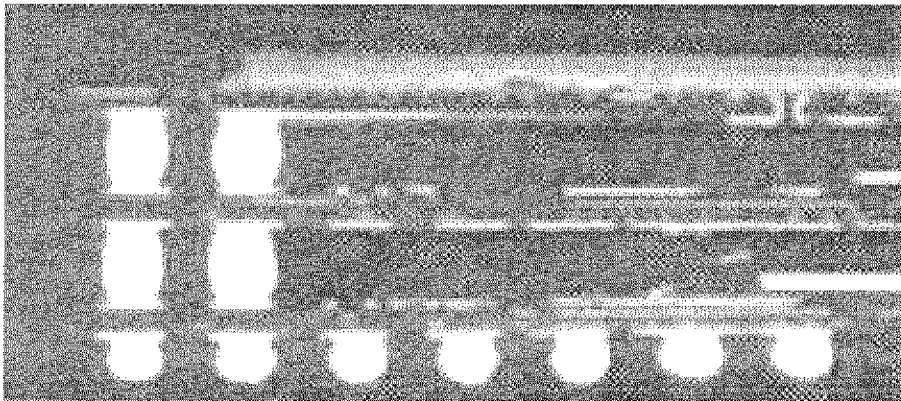
- Current and future package options mix and match elements in almost infinite combinations
- Elements include:
 - Wire bonds
 - Ball interconnects
 - Solder joints
 - Conductive epoxies
 - Vias
 - Multi-layer substrates
 - Multiple chips, active and passive (hybrid?)
 - Stacking of components
 - Embedded actives and passives
 - Polymers
 - Ceramics
 - Enclosures/encapsulants
 - Thermal control features



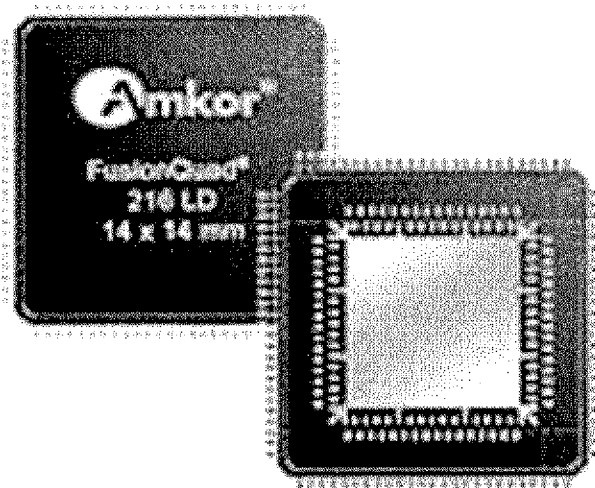
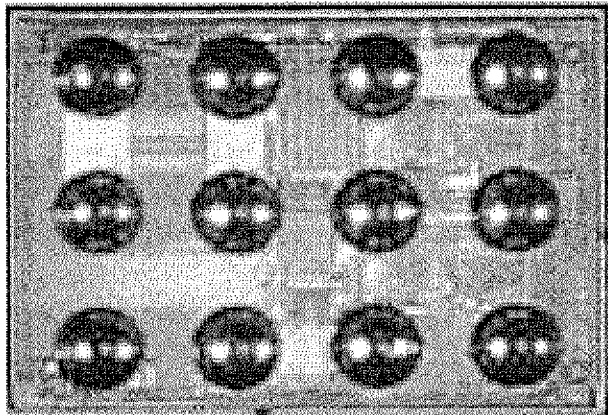
Some Large Device Package Options



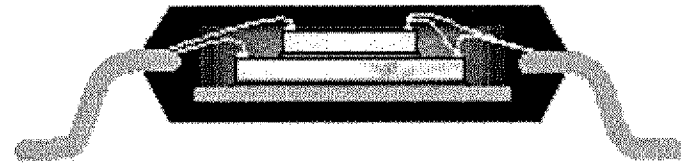
Embedded Capacitor



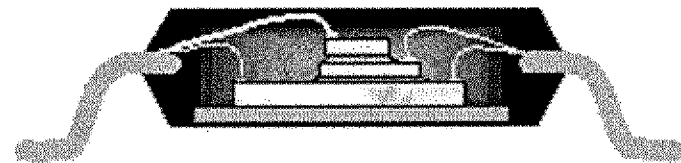
Some Large Device Package Options



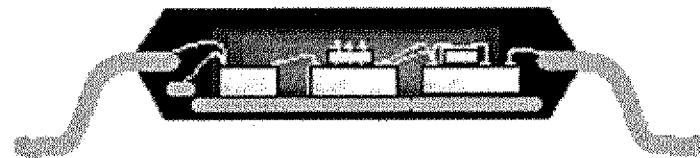
2 Die Stack



3 Die Stack



**6 Die Multi-Chip Module
Stacked Die ePad LQFP**



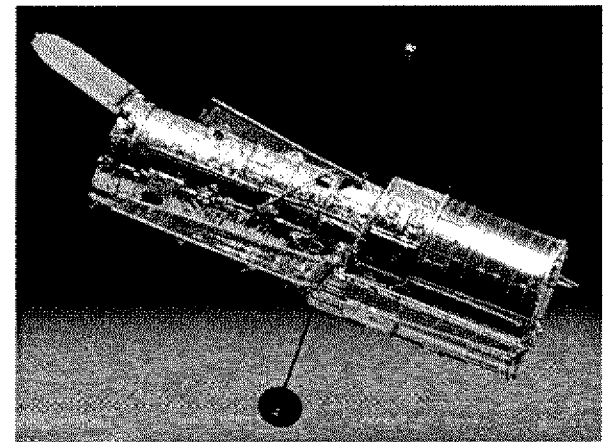
From Amkor's Website <http://www.amkor.com/go/packaging>

More Complexity is Coming

- **Stacking of chips to provide a third dimension of density and complexity**
 - **Stacking of Field Programmable Gate Arrays (FPGAs) appears imminent**
 - **Stacking of memory die is “old hat”**
 - **Through-silicon vias instead of bond wires**
 - **Maintain speed and allow lots of I/Os**
 - **High volumetric efficiency**
 - **Significant manufacturability challenges**
 - **Material and dimensional interfaces**
 - **Testability**
 - **Significant usability challenges**
 - **Design complexity**
 - **Handling, testing, rework/replace, risk management**
 - **Cost versus benefit trades**

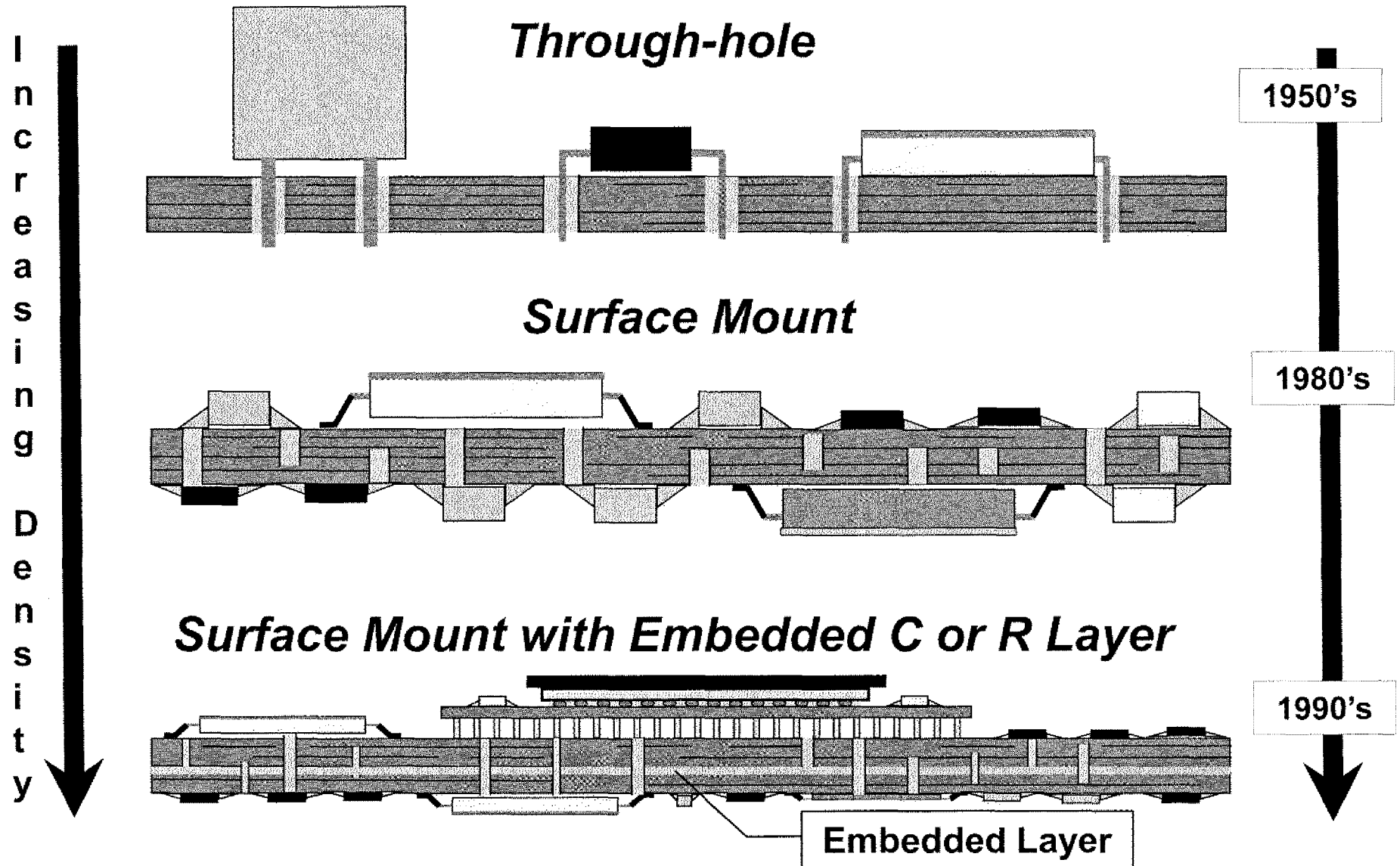
MIL-PRF-38535, Class Y

- “Y Not” Non-hermetic for Space?
- Proposed new class for M38535, monolithic microcircuits
- Class Y will be for Space level non-hermetic
- Class V will be defined as hermetic only
- Addition to Appendix B, “Space Application”
- Package-specific “integrity” test requirements proposed by manufacturer, approved by DLA* and government space
- The Package Integrity Test Plan must address:
 - Potential materials degradation
 - Interconnect reliability
 - Thermal management
 - Resistance to processing stresses
 - Thermo-mechanical stresses
- G12 Task Group established 01/13/01



* MIL spec qualifying activity Defense Logistics Agency, Land and Maritime

Level 2 Packaging Evolution



Embedded Technologies + and -

- **Advantages:**

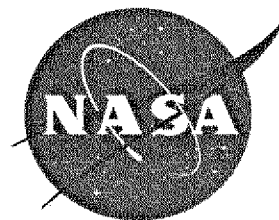
- Increases volumetric efficiency – reduces parts count on Printed Wiring Board (PWB) surface
- Enhances performance – speed
- Increases reliability (reduces number of solder joints)
- Distributes heat more evenly
- Aids high volume production and reduces cost

- **Challenges:**

- Design/layout – introduces constraints, complicates re-spin
- PWB quality – more difficult PWB fabrication
- PWB robustness – material mismatches
- Testing – can't access individual parts
- Rework and repair – problems buried inside PWB
- “One-offs”

NEPP Activities

- **Continuous surveillance of emerging trends**
- **Have evaluated embedded passives**
 - Partnering with Navy Crane
 - Quite mature technologies, bulk capacitive layer
 - Works but “space” low quantities a challenge
- **Have tried to evaluate a novel, flexible, embedded active-die technology**
 - Considerable promise
 - Beset by technical problems, particularly die thinning
 - Consider revisiting as technology improves
- **Initial evaluations of technical readiness of die thinning, through-hole vias and advance die stacking are needed**
- **Continue development of Class Y concept**



<http://nepp.nasa.gov>